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FINAL REPORT

UTILITY OF EMULATION AND SIMULATION COMPUTER MODELING OF SPACE STATION ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

BY

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ABSTRACT

Over the years, computer modeling has been used extensively in many disciplines to solve engineering problems. A set of computer program tools has been proposed to assist the engineer in the various phases of the Space Station program from technology selection through flight operations. This report focuses on the development and application of emulation and simulation transient performance modeling tools for life support systems.

The results of the development and the demonstration of the utility of three computer models are presented. The first model is a detailed computer model (emulation) of a solid amine water desorbed (SAWD) CO_2 removal subsystem combined with much less detailed models (simulations) of a cabin, crew, and heat exchangers. This model was used in parallel with the hardware design and test of this CO_2 removal subsystem. The second model is a simulation of an air revitalization system combined with a wastewater processsing system to demonstrate the capabilities to study subsystem integration. The third model is that of a Space Station total air revitalization system. The station configuration consists of a habitat module, a laboratory module, two crews, and four connecting nodes.

FOREWORD

This report has been prepared by Hamilton Standard Division of United Technologies Corporation for the National Aeronautics and Space Administration's Langley Research Center in accordance with Contract NAS1-17397, "Development of an Emulation/Simulation Computer Model of a Space Station Environmental Control and Life Support System (ECLSS)". This report summarizes the results of that contract.

Appreciation is expressed to the Technical Monitors, Messrs. John B. Hall, Jr., and Lawrence F. Rowell of the NASA Langley Research Center for their guidance and advice.

This report was written by Dr. James L. Yanosy, Program Engineer. The early phases of the program were conducted under the direction of Albert Boehm and Harlan Brose, while the latter phases were conducted under the direction of John M. Neel, the current Program Manager. Thanks are extended to Stephen Giangrande, Joseph Homa, Gordon Allen and Robert Blakely for their technical contributions. Appreciation is given to Messrs. Raymond Trusch and Edward O'Connor for their advice and direction.

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1.0 INTRODUCTION

Computers, since their inception, have been used to solve engineering problems in many areas. In thermal applications, computer programs may be used to predict temperatures throughout a piece of metal; in structural applications, they may be used to determine stresses and strains in various structural members. Still another application is to simulate the dynamic performance of a system.

With the advent of the Space Station program, the role of computers in the engineering process is being further explored. Hall [1]* and Blakely and Rowell [2] have reviewed the engineering process and have proposed various computer tools that could assist the engineer at various phases of the process. These tools have been lumped together and are called the Emulation, Simulation, Sizing, and Technology Assessment Program (ESSTAP).

The relationship between the software and the hardware envisioned for the engineering process is illustrated in Figure 1. The process begins with a technology assessment computer program which assists the engineer in making the selection of the technology deemed best for an application based on various factors such as weight, power, volume, cost, safety, reliability, etc. With the technology selected, the design process begins. In this phase, another computer program would

*Numbers in brackets denote references listed in Section 5.0

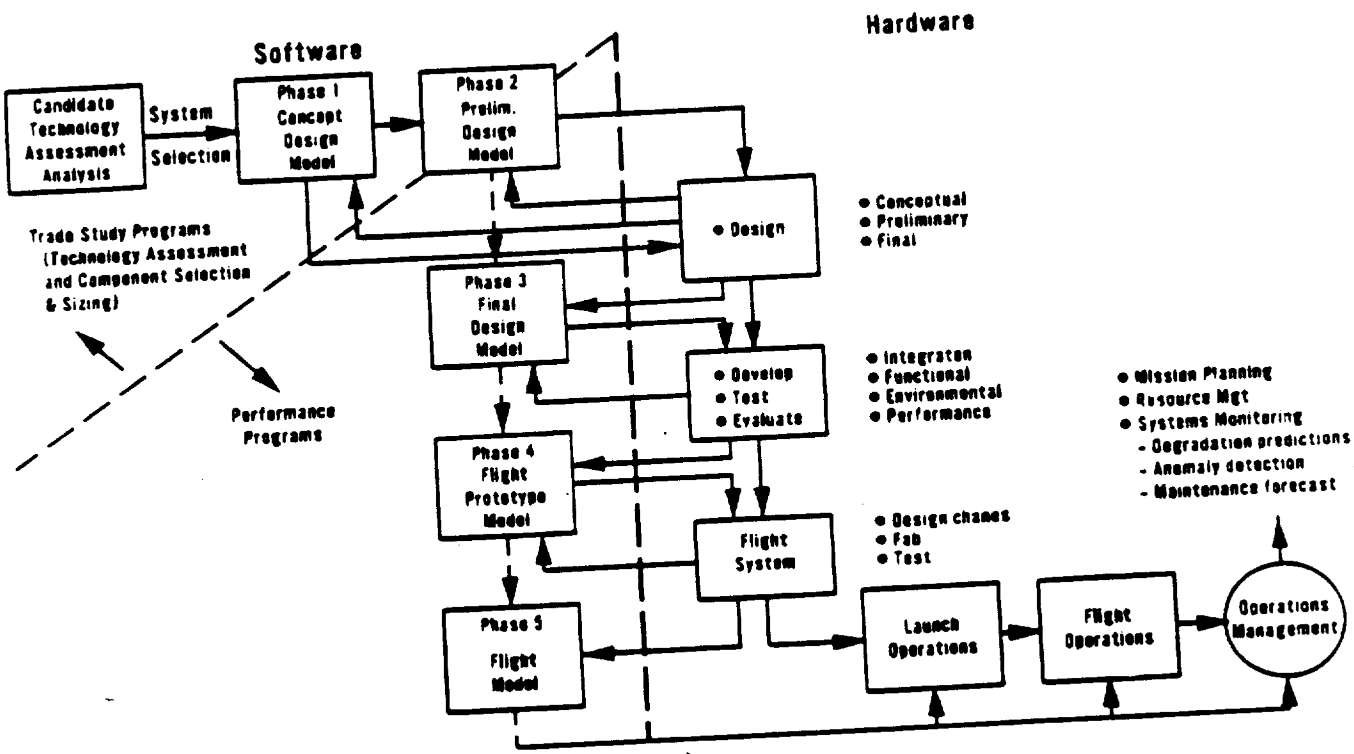

Figure 1. Application of Software Tools to the Design and Operations Phases of a Flight System

1.0 INTRODUCTION (Continued)

assist the engineer in sizing the hardware. For example, the mass of material for a chemical process bed or the number and size of tubes for a shell and tube heat exchanger could be determined from a computer program.

Next, performance simulation programs would be written to assist the engineer in various aspects of design, development, test, and flight of the hardware.

The concept of levels of computer programs was then introduced by Blakely and Rowell [2]. Essentially, transient performance simulation computer programs could be written to model a subsystem at various depths of detail. The first level performance program would simply consider the subsystem as a black box and be only interested in the input and output characteristics. This model of a subsystem could be used in a larger system model to determine overall system performance. The next level of detail is to model each of the components in the subsystem as a black box. The final and deepest level is to model each component in the subsystem in detail. This detailed model aims to describe in mathematical formulations the physical and chemical processes of a component. Black box models are referred to as simulations, whereas the in-depth models are referred to as emulations. Of course, in modelling a subsystem, black box models of components can be combined with detailed models of other components to create an emulation-simulation model.

1.0 INTRODUCTION (Continued)

Each of these levels can be used for various applications in the engineering process. The first level performance program could be used to study interactions of pieces of equipment in an entire system. On the other hand, the emulation level could be used to assist in test, fault isolation, and hardware development.

Development of the first two tools of ESSTAP was conducted prior to this contract effort. A description and presentation of the first tool called the Technology Assessment Program was given by Hall, et al [1,3]. This program evaluated various technologies for a given function and permitted graphical presentation of the results. Various weighting factors could be applied to weight, power, volume, etc. The program would then tally the results for each technology and present comparisons. A sizing program for potential Space Station technologies was discussed briefly by Blakely and Rowell [2].

However, the performance simulation tools needed development and exploration to determine their utility and to determine what level performance simulation program best suited the various phases of the engineering process. Hamilton Standard was given a contract by the Langley Research Center to develop and explore simulation programs. This would thereby complete and demonstrate the effectiveness of ESSTAP tools.

1.0 INTRODUCTION (Continued)

The procedure required first selecting the type of Space Station System which would best demonstrate the approach. Next, a hardware component in its development stages must be selected to investigate the utility of in-depth emulation computer programs. Lastly, models must be developed to explore the utility of simulation programs.

2.0 PREVIOUS WORK

Computer simulations in life support systems have been conducted in the past. Trusch, et al [4] performed simulations for the Space Station Prototype program in 1971. A regenerative life support system in a cabin with a crew was simulated using the G189 ECLSS analyzer [5]. The program was used to verify design sizing of the liquid cooling loop and to verify the adequacy of the cabin dew point temperature control. Both of these verifications required system transient analyses. The models were all simulation or first level performance models and were never coordinated with actual hardware development.

Another report [6] published by Hamilton Standard on the Space Station Prototype presents some experiences with the G189 computer simulation program. Some of these are:

(1) The SSP computer effort was running to catch up as opposed to being the design tool it was intended.

(2) More staffing was needed than it had.

(3) As the level of detail or complexity of simulation increases, the program loses its flexibility and attractiveness.

2.0 PREVIOUS WORK (Continued)

(4) The computer program was most cost effective in the preliminary design where a deep level of detailed modeling was not necessary and transient analyses were required.

Again the combination of an emulation and a simulation was not investigated nor was there a tie between the simulation and actual hardware development.

A paper by Lafuse [7] presents the application of a generalized transient computer program ARPCS2AT2 for Shuttle atmospheric pressure and composition control analysis. The program's main applications have been in the area of test support and analysis of proposed flight procedures. In test support, the model was used to make pretest predictions and then to explain the actual data. For flight procedures, the program was used to evaluate the use of an oxygen mask in the Shuttle.

Yanosy [8] with a computer simulation program called FLASH was able to assist in fault isolation of a flash evaporator exit temperature instability observed on STS-3. The computer simulation program showed that a higher midpoint temperature sensor time constant could cause the observed instability.

2.0 PREVIOUS WORK (Continued)

In summary, computer simulation programs have been shown to be of assistance on certain phases of the engineering process. What has not been done is to explore the utility of a combined emulation simulation program and to determine the utility of the various levels of simulation programs in the various phases of the engineering process.

3.0 INVESTIGATIONS

The following sections summarize the results of the investigations conducted under this contract to explore the utility of various performance simulation models in the engineering process. The investigations are first to select the systems to simulate and emulate, develop and explore the utility of the emulation simulation performance model, and lastly to develop and explore the utility of two different, higher-level, simulation models.

3.1 Requirements Evaluation and System Selection

The initial phase of the contract required that goals of the study be well defined so that the proper target subsystem could be identified. The requirements evaluation task consisted of:

(1) Verify computer program (G189A) compatibility with LaRC computer.

(2) Establish potential uses of Space Station computer models identified by the ESSTAP approach.

(3) Establish life cycle cost reductions.

(4) Identify the levels of programs best suited for the various phases of the engineering process.

(5) Verify baseline ECLS design loads.

3.1 Requirements Evaluation and System Selection (Continued)

The system selection task objective was to review and evaluate all subsystems comprising the ECLSS and select one for which an emulation/simulation model would be demonstrated.

The results of this initial phase was reported by Blakely [9]. In summary, the following results were obtained:

(1) The G189A was found to be portable to the Langley Research Center's PRIME computer.

(2) Potential uses for the ESSTAP computer models were identified and are listed here in Table 1.

(3) Areas where cost reductions could be realized were identified for the various phases of the engineering process.

(4) Performance program levels best suited for the engineering process phases were given. Essentially, steady state trade study programs were best suited to the conceptual study phase and candidate technology assessment phase. During preliminary design, a simple transient simulation model is best suited. As the program passes to development, test and flight, the simulations must be more detailed to the emulation level.

3.1 Requirements Evaluation and System Selection (Continued)

(5) Baseline design ECLS loads were verified.

(6) A sub-group of the air revitalization system was selected for the ESCM program where the SAWD CO_2 removal subsystem would be modeled in detail.

3.2 ESCM

The first computer model produced under the contract was a combined emulation/simulation model. The model consisted of a cabin, crew, sensible heat exchanger, condensing heat exchanger, oxygen and nitrogen control, and a SAWD carbon dioxide removal subsystem. Except for the SAWD, all components were simulations - lightweight models. The SAWD, however, was emulated. A detailed model was made of the SAWD bed and each component in the SAWD subsystem was modeled. Figure 2 shows a G189A [5] schematic of the system modeled.

The intention of this emulation model was to demonstrate its utility in the design, development, and testing of a piece of hardware. After testing, the model was to be updated to reflect any hardware modification.

Table 1
Potential Uses For ESSTAP Computer Models In The Space Station Engineering Process

A. Concept Development (Trade Studies)
1. Establish baseline ECLSS's and growth scenarios.
2. Select candidate subsystems to be investigated.
3. Determine overall power, weight, and volume requirements.
4. Evaluate overall program life cycle costs.
5. Study impact of different redundancy and reliability requirements.
6. Determine key ECLSS parameters that drive overall Space Station design and configuration.

B. Preliminary Design
. 1. Study methods of integrating candidate subsystems into an operational ECLSS.
. 2. Define operational schematics and determine interface requirements.
. 3. Evaluate preliminary design assumptions and study effects of component or subsystem placement, substitution, and size selection.
. 4. Determine effects of growth scenario phasing on life cycle costs and performance capabilities.
. 5. Iterate configuration and design assumptions to optimize performance and cost factors and to generate data required for Requirements Definition Documents (RDDs).

C. Design, Development, Test and Engineering (DDT&E)
. 1. Generate detailed component and subsystem specification data and establish their true and/or critical range of operating conditions as a result of their integration into an ELCSS.
. 2. Define accurate interface requirements for the purpose of preparing Interface Control Documents (ICD's).
. 3. Define component and subsystem test conditions, generate pretest predictions, and correlate test results.
– 4. Provide specification and ICD change requirements resulting from upgraded models obtained by correlating test data.
+ 5. Perform Failure Mode and Effect Analyses (FMEA).
. 6. Determine component, subsystem, and system off-design performance.
. 7. Further evaluate ECLSS growth scenarios and define interface requirements and effects of proposed changes.

D. Mission Planning and Flight Operations
+ 1. Evaluate proposed electrical and crew activity timelines and determine mission constraints.
+ 2. Provide realistic ECLSS response data for crew training simulations.
+ 3. Simulate failure modes and determine contingency and/or emergency procedures.
+ 4. Define user or experiment interface requirements, constraints, and capabilities.
+ 5. Evaluate operational performance anomalies to determine equipment degradation, failure or pending failure conditions.
+ 6. Provide trending analyses to determine required response time to prevent critical conditions from occurring.
+ 7. Study effects of experiment integration and component or subsystem replacement due to Space Station growth.

KEY:

– Not done.

. Potential uses that were demonstrated during this ESCM contract.

+ Recommended future work.

NOTES: Phase A of the engineering process is not a phase for the application of Emulation Simulation Computer Modeling Tools.

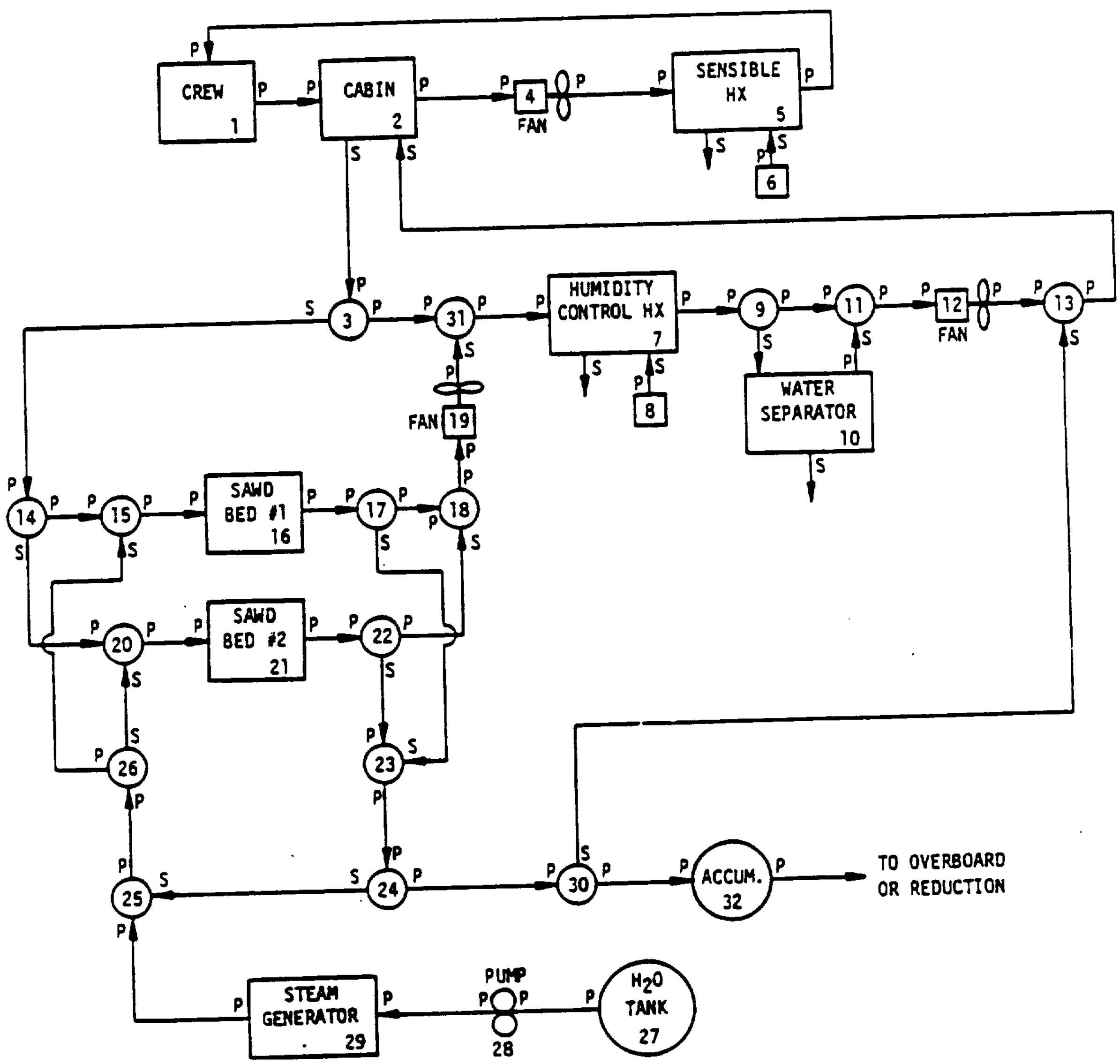

Figure 2. G189A Schematic of System Modeled for ESCM

3.2.1 Publications

A G189A model of the selected system was developed. A User's Manual [10] and a Model Description Document [11] of the computer program were published. The User's Manual provides the user with instructions to run the computer program, a brief overview of G189A, a presentation of the input and output of each subroutine, and a sample problem.

As a result of testing, recommended improvements suggested by Langley Research Center, and further development of the SAWD model, updates to the User's Manual and Model Description Document were published in the form of appendices [12,13]. These appendices also present the results of other simulations to be discussed in Section 3.3.

In addition to these reports, a paper [14] about the utility of ESCM was presented at the Fifteenth Intersociety Conference of Environmental Systems. The paper presented simulation benefits from the model during the design, development, and testing of an ARS hardware component. Benefits were demonstrated in subsystem sizing to meet design requirements, subsystem configuration, control and operating mode optimization, test planning, and cost benefit. Of the applications of the ESSTAP tools listed in Table 1, those demonstrated with ESCM are noted in the Table.

3.2.2 SAWD Experience

The ESCM was used in conjunction with the design, development, and test of an ARS component - the SAWD. The uses of the computer program prior to testing are presented in the paper by Yanosy and Rowell [14]; this section presents benefits of the ESCM during the actual SAWD test phase of the engineering process.

First of all, the control logic originally programmed into ESCM needed to be updated to represent the logic which existed at the time of testing. This logic was substantially different from the original relative humidity method. The program identified areas of the SAWD control logic which would require further development. When the unit subsequently went on test, the test experience with the control logic was consistent with that shown by the computer model.

Although the program demonstrated that the SAWD control would require further development, the SAWD hardware experienced difficulties in testing that could not have been predicted using the model. A list of sample SAWD initial testing difficulties is presented in Table 2 along with comments as to the utility of the ESCM. In summary, a computer model, to have foreseen all the difficulties, would have to have been an emulation of each and every component of the SAWD including the controller.

Table 2

SAWD Hardware Test Experiences and Related ESCM Effectiveness

EXPERIENCE	CONTROLLER CHANGE	ESCM UTILITY
1. Water pump flow unexpectedly low.	1. Modified Interpolation table to reflect calibration.	1. ESCM showed the proper flow to be delivered. Assist in fault isolation.
2. Fan flow unexpectedly low.	2. Modified Interpolation table to reflect calibration.	2. ESCM showed the proper flow to be delivered. Assist in fault isolation.
3. Steam generator control and safety RTD's on same circuit board.	3. Put on separate A/D circuit boards.	3. No utility. Strictly a safety philosophy implementation.
4. Trend data not recorded properly.	4. Changed timing for sending cyclic trend data to display control.	4. No utility. ESCM did not model trend data gathering.
5. Control of absorption cycle times is unstable.	5. Changed bed mass const. k13 from 9.35 to 8.50.	5. ESCM showed cntrl. problems and need to review cntrl. laws.
6. Condensation in steam generator and lines.	6. Maintain steam generator energized during energy transfer and if desorb ends prior to start of absorb.	6. No utility. ESCM did not model stm. generator and its plumbing lines in detail.
7. Control of absorption cycle times is unstable.	7. Clamp controller calc. CO_2 flow exiting canister to a value above zero.	7. No utility. ESCM in its modeling of cntrl. laws already had the clamp.

Table 2

SAWD Hardware Test Experience and Related ESCM Effectiveness

(Continued)

EXPERIENCE	CONTROLLER CHANGE	ESCM UTILITY
8. Control of absorption cycle times is unstable.	8. Correct error in absorption mass flow calculation.	8. ESCM showed cntrl problems and need to review cntrl. laws.
9. Startup cycle is too long.	9. Reduce startup cycle from 55 minutes to 50 minutes.	9. ESCM showed startup cycle to take only 39 minutes.
10. Conflict between pressure regulator and upper limit to open CO_2 Reduction Valve.	10. Change pressure to open CO_2 Reduction Valve from 30.0 to 29.5 psia.	10. Conflict shown in ESCM also.
11. Valve to direct CO_2 to accumulator rather than cabin directed flow to accumulator too quickly in desorb.	11. Increased flow setting at which flow is to be directed to accumulator from 0.01 to 0.0275 cfm.	11. ESCM demonstrated need to increase flow setting as initial ullage flow is high.
12. Canister inlet valve did not reach proper position for Bleed phase.	12. Reduced drive time to inlet valve from 7.5 to 1.6 seconds.	12. ESCM did not emulate inlet valve drive time.
13. Bleed phase of cycle is too long.	13. Reduced Bleed Phase from two to one minute.	13. ESCM showed system takes a short time to bleed down.
14. Possible draw of air into system through valve which directs CO_2 flow to accumulator during Energy Transfer.	14. Position valve to accumulator rather than the cabin during Energy Transfer.	14. No utility. ESCM did not emulate pressure drops through SAWD.

Table 2

SAWD Hardware Test Experience and Related ESCM Effectiveness

(Continued)

EXPERIENCE	CONTROLLER CHANGE	ESCM UTILITY
15. Spurious low bed inlet temperature warning during Energy Transfer.	15. Increased time to reach 130 F from 60 to 90 seconds. Time to reach temp. took longer than initial guess.	15. Warning and alarm logic were not modeled as part of ESCM.
16. Shutdown occurs if absorption ends before desorption.	16. No shutdown. Simply reduce fan speed until desorption is done.	16. ESCM did not model shutdown logic but did predict absorb ending before desorb.
17. Control of absorb cycle times is unstable.	17. Add a new algorithm to calculate CO2 loading.	17. ESCM showed cntrl problems and need to revise control laws.
18. Control of absorb cycle times is unstable.	18. Change algorithms to calc bed water loading and absorb cycle time.	18. ESCM showed cntrl problems and need to revise control laws.
19. Shutdown on fan speed.	19. Change fan speed shutdown ranges to less than 1200 or greater than 5500 RPM.	19. No utility. ESCM did not model fan speed nor shutdowns.

3.2.2 SAWD Experience (Continued)

With respect to the development of the SAWD, the IR45-amine is no longer manufactured and a new amine is used instead. It is chemically similar but performs better than the original IR45. Higher CO_2 loadings are attainable with a crisper breakthrough curve. Therefore, with respect to computer model development, the SAWD model needs to be revised to reflect the characteristics of the new amine.

The actual utility of the model during test was not thoroughly demonstrated because of: (1) insufficient funding for modeling development, and (2) some hardware difficulties encountered by the SAWD were not amendable to solution by the present model. A period is needed where the model and hardware develop and iterate in parallel such that at the end of the development testing, the model and hardware agree. Funding was only available for hardware development, and additional funding was not available for modeling development. Nevertheless, the program showed its utility in the control area, and its potential uses in further testing are certainly attainable.

3.2.3 Installation on the PRIME

The ESCM program when installed on the PRIME produced different answers from the ESCM installed on the Hamilton Standard IBM. After some judicious selection of options available on the PRIME FORTRAN compiler, such as rounding, the answers were in much better agreement but still not as close as would be expected.

3.2.3 Installation on the PRIME (Continued)

The problem still exists and the difficulty appears to lie in the SAWD bed subroutine iteration. Several changes were made to the iteration procedure as described in the ESCM Model Description Appendices [13]. These changes need to be evaluated to see if agreement is improved.

3.3 Simulation Computer Models

Two simulation computer models were developed to demonstrate the utility of a different level of performance ESSTAP tool. One simulation consists of an air revitalization system and a wastewater management system linked together. The other simulation concentrates on the air revitalization system alone but applies it to an entire Space Station complete with a habitat, laboratory, four nodes and two crews.

G189A schematics of the two systems are shown in Figures 3 and 4. The combined air revitalization system and water management system model is called ECLSB while the other simulation is called the Space Station Model.

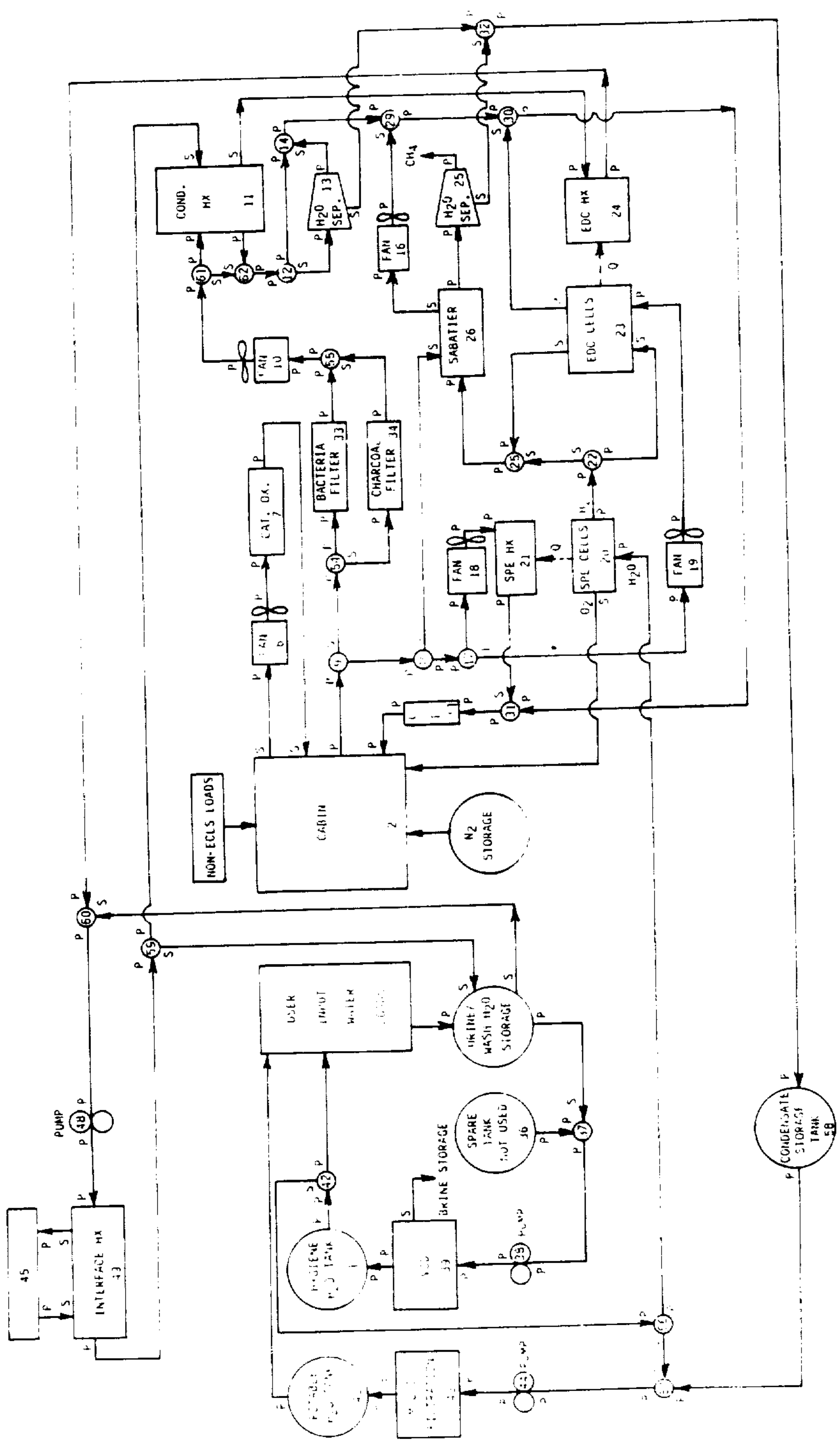

Figure 3. G189A Schematic of ECLSB

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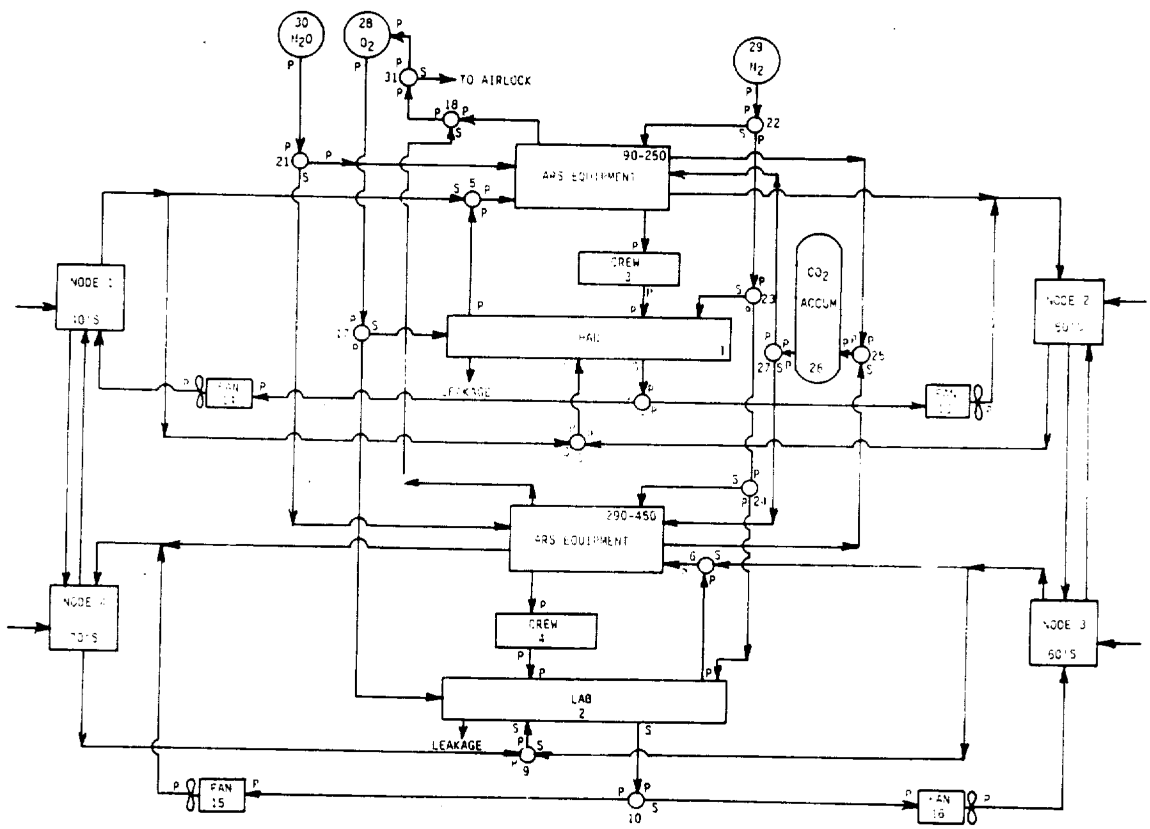

Figure 4. G189A Overview Schematic of Space Station Model

3.3.1 Publications

A separate User's Manual [15] was originally written for the ECLSB simulation model. Later, it was decided to write appendices to the original ESCM User's Manual [10] and Model Description Document [11]. Included in these appendices are:

Appendix	Title
A	ESCM Update
B	ECLSB
C	Space Station Model

Both Appendices to the User's Manual [12] and Appendices to the Model Description Document [13] are arranged in the same manner. The separate ECLSB User's Manual [15] is simply referenced in Appendix B of the Appendices to the User's Manual document [12].

3.3.2 Utility of Simulation Models

A simulation model of a system consists of lightweight models of the various subsystems within the system. This simulation model can then be used to assist in the preliminary design of a system and in the design, development, and test of a system as delineated in Table 1.

3.3.2 Utility of Simulation Models (Continued)

Several useful functions of the simulation models have already been demonstrated. For example, one area of intense interest is the study of a system's capability to handle transients in a manner to meet specifications. From the sample problem given in the Space Station Model User's Manual [12], Figure C-16 shows that the carbon dioxide level in the habitat exceeds the specification limit of 3.0 mm Hg. This figure is repeated here in Figure 5. This indicates a larger CO_2 removal unit is needed to handle the transient CO_2 loads throughout a day for the case where the full crew of eight people are all in the habitat.

Another example is in the area of integrating candidate ARS subsystems into an operational ARS. The configuration shown for the Space Station Model is one configuration; other configurations like bussing of carbon dioxide could be explored.

Another example is in the control of the subsystems. Each subsystem has its own control, yet a total system control is needed to regulate the amount of carbon dioxide delivered to a CO_2 reduction unit or how much hydrogen to vent. Questions like these must be answered as part of a simulation model. The simulation thereby focuses on system control problems and their solutions early in the design phase. Potential impacts on system configuration, sizing, and technology selection can be evaluated.

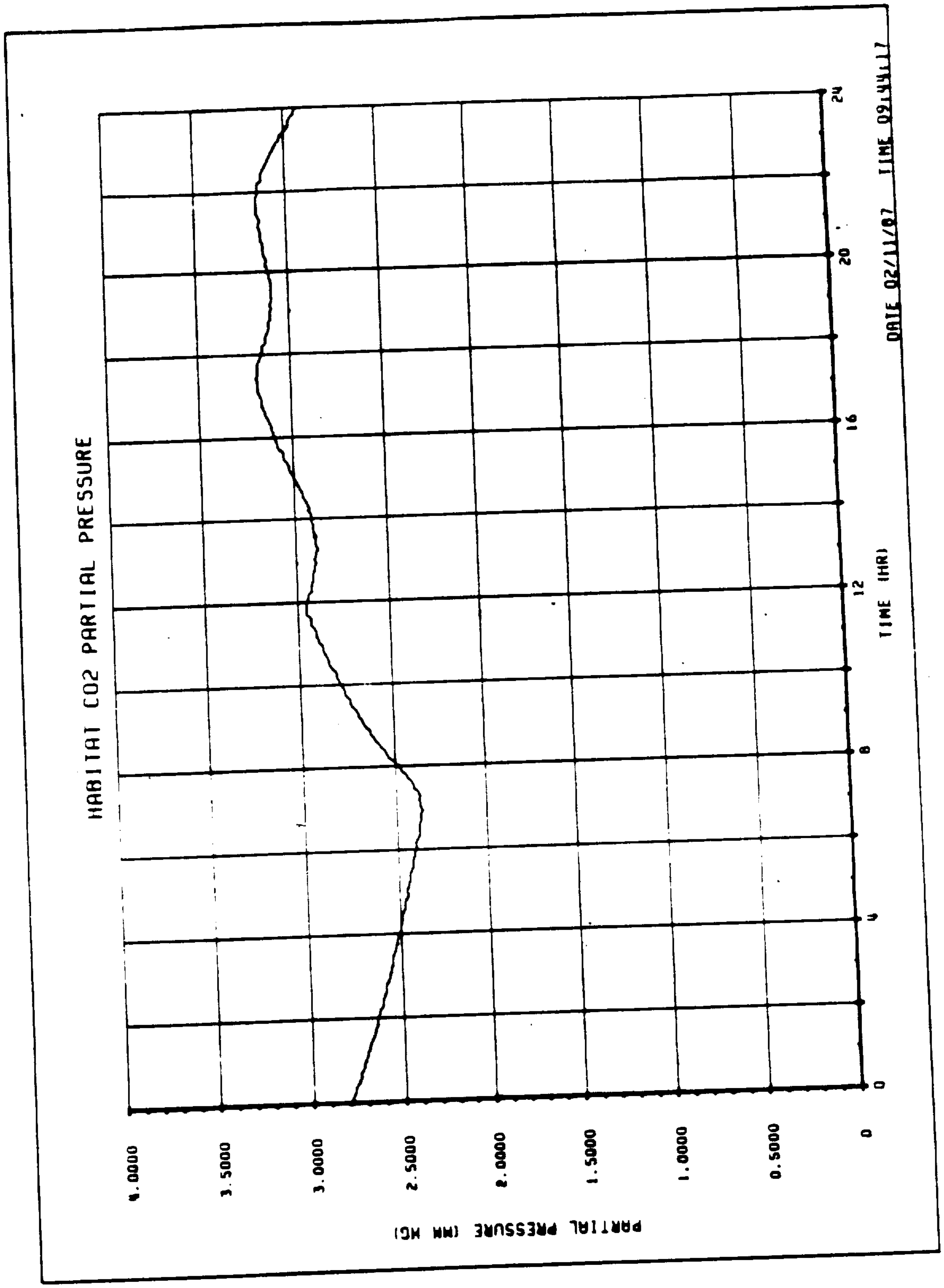

Figure 5. G189A Simulated Space Station CO_2 Daily Transient

3.3.2 Utility of Simulation Models (Continued)

With this simulation model, subsystems of the same function can be interchanged and the impact on overall system performance can be assessed. For example, a molecular sieve CO_2 removal unit can be studied and then replaced by an EDC or SAWD. The ability of each of these to handle transient loadings or their impact on system oxygen and humidity levels can be easily evaluated.

Pretest predictions of subsystems plumbed together can be generated as well as Failure Mode and Effect Analyses (FMEA's) performed in the event one subsystem fails.

With the integration of the water and the air systems as done in ECLSB, crew timelines for shower, washing, and eating can be studied to examine their impact on cabin humidity levels, water tank storage and level control, and water availability.

3.3.3 G189A Limitations

While G189A is an excellent tool for ECLSS transient analyses, it has certain limitations which hinder its utility.

3.3.3 G189A Limitations (Continued)

One of these limitations is the speed with which a model can be generated from scratch. First a schematic must be generated on paper, then a great deal of bookkeeping performed to connect one subsystem to the next, and then a solution path must be defined. This process is similar to that for a heat transfer problem where the item to be analyzed is divided into a fine grid mesh. A simpler procedure is needed that would eliminate the bookkeeping.

Secondly, any changes that need to be made such as plumbing or configuration changes require major work to modify the connections between components and then to redefine the solution path. Again a system that would perform this bookkeeping would save much time and eliminate the limitation on the utility of the G189A program.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The ESSTAP tools defined for the various phases of the engineering process were identified; and, in this contract, the performance simulation tools of ESSTAP were developed and their utility demonstrated.

Emulation combined with simulation was found to be useful in both the design and testing phases of the engineering process. Design verification, test planning, control analysis, and a better understanding of the physical and chemical processes were some of the chief benefits. However, many engineering difficulties encountered during the test of the SAWD could not be foreseen or analyzed with the ESCM. In order to do so would have required an emulation level model of every component in the system including the piping and controller. The cost effectiveness of that many emulation models is doubtful.

Lightweight, simple, simulation models of subsystems are excellent in the early stages of system design, development, and test. They can assist the engineer in many ways to optimize the size and configuration of the system.

Based on the results of this contract, the following conclusions and recommendations are made:

4.0 CONCLUSIONS AND RECOMMENDATIONS (Continued)

(1) Model depth must match the model application to realize the most benefits and be the most cost effective.

Level	Applications
Simulation	. Study system control early in the design phase.
	. Explore gas bussing options.
	. Include effects of transients on subsystem sizing
	. Explore effects of different technologies on system operations.
	. Make pretest predictions for system tests.
	. Perform FMEA's on a system level.
	. Study crew induced loads and their distribution.
Emulation	. Study and understand component behavior.
	. Make pretest predictions.
	. Assist in component design and sizing.
	. Perform failure analysis.
	. Develop simulation models of a component.

4.0 CONCLUSIONS AND RECOMMENDATIONS (Continued)

(1) Model depth must match the model application to realize the most benefits and be the most cost effection.

Level	Applications
Emulation Simulation	• Study subsystem size as a affected by system operation. • Study component integration options. • Plan tests. • Perform subsystem failure analyses. • Optimize subsystem control. • Verify designs.

(2) Various level models must be ready prior to program phase need or computer effort will always play catch-up to hardware. Adequate staffing and funding are required.

(3) All difficulties in the developmental testing of hardware cannot be foreseen with Emulation Simulation Computer Modeling. All components would have to be emulations.

(4) Emulation and simulation models of a subsystem should be developed by the subsystem manufacturer as appropriate with the development of the hardware.

(5) As the level of detail or complexity of simulation increases, the more difficult, time consuming, and costly is the task to keep pace with hardware developmental changes.

(6) Computer simulation validity must be established early in Hardware Program to obtain support.

(7) The models developed should be in the form of subroutines structured in such a manner to be easily inserted into an ECLSS analyzer such as G189A.

(8) An ECLSS analyzer should be developed that eliminates the bookkeeping required with the present G189A in setting up a model.

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15. Supplementary Notes

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16. Abstract Over the years, computer modeling has been used extensively in many disciplines to solve engineering problems. A set of computer program tools has been proposed to assist the engineer in the various phases of the Space Station program from technology selection through flight operations. This report focuses on the development and application of emulation and simulation transient performance modeling tools for life support systems.

The results of the development and the demonstration of the utility of three computer models are presented. The first model is a detailed computer model (emulation) of a solid amine water desorbed (SAWD) CO_2 removal subsystem combined with much less detailed models (simulations) of a cabin, crew, and heat exchangers. This model was used in parallel with the hardware design and test of this CO_2 removal subsystem. The second model is a simulation of an air revitalization system combined with a wastewater processing system to demonstrate the capabilities to study subsystem integration. The third model is that of a Space Station total air revitalization system. The station configuration consists of a habitat module, a laboratory module, two crews, and four connecting nodes.

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